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A PROCESS VIEW ON MANAGING QUALITY DURING THE CREATION OF TECHNICAL INNOVATIONS: LESSONS FROM FIELD RESEARCH

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Goal: TQM establishes quality enhancement as a vital priority for long-term effectiveness and survival. In the longer run, quality improvement leads to decreasing costs. It may even facilitate the attainment of other objectives.

Definition of quality: Following Kano (cited in Deschamps and Nayak, 1995), quality is satisfying or delighting the customer. All TQM initiatives must therefore begin with a thorough understanding of customer perceptions and needs.

Role/nature of environment: TQM blurs intra- and inter-organisational boundaries. Entities previously regarded as "distinct" or as "outsiders" now become embedded in organisational processes.

Role of management: Management has to create commitment and consistency of purpose. Also management has to create the system necessary to produce high quality outcomes.

Role of employees: Employees help shape the quality process. They build relationships (e.g. active information-seeking behaviour) and take the steps necessary to improve quality within the system designed by management. Training and education to support this involvement are provided.

Structural rationality: The organisation is perceived and configured as a set of horizontal processes that explicitly incorporate the many ongoing customer-supplier relationships.

Commitment to change: Organisational members are motivated to avoid a steady-state environment. Change and innovation are encouraged.

This overview relates TQM's operational characteristics to its organisational implications. But even so, TQM remains deeply rooted in managerial practice. Therefore, recent academic work has started to scrutinise the fits and gaps between current TQM practices on the one hand (both as they are divulged by their "founding fathers" like Deming, Juran and Ishikawa; and, as they are found in managerial practice today), and management theory development on the other hand (see for example: Hackman and Wageman, 1995, or, Spencer, 1994).

To this end, Spencer examines TQM in relation to mechanistic, organismic, and cultural models of organisation. Her approach is a highly useful starting point for our exploratory research, namely the development of a conceptual approach toward TQM that can work during a technical innovations. The three models of organisation she describes, can be related to the potential of TQM to influence both management theory and practice. More precisely, Spencer's view enables a process approach to implementing TQM for activities characterised by high degrees of uncertainty and ambiguity. This is particularly relevant for technical innovation activities. However, before examining the interactive design of a TQM process along the innovation trajectory, a more fundamental question has to be addressed.

Defining and operationalising TQM. Hackman and Wageman (1995) conducted an adapted version of Campbell and Fiske's convergent and discriminant validity test to examine whether there exists *"such a thing as TQM."* Convergent validity reflects the degree to which the versions of TQM originated and divulged by its founders and observed in organisational practice share a common set of assumptions and prescriptions. Discriminant validity refers to the degree to which TQM philosophy and practice can be reliably distinguished from other strategies for organisational improvement, such as participative management, management by objectives, and so on.

Both scholars conclude that TQM passes the convergent validity test. They report substantial agreement among the movement's founders about the key assumptions and practices of total quality management. Moreover, they state: *"contemporary TQM practice is generally consistent with the founders' ideas. (...) We find that there is impressive convergence — across theorists, across practitioners, and across time — of the basic ideas of total quality management"* (Hackman and Wageman, 1995: 318). With respect to the discriminant validity, both researchers are much less optimistic. Their conclusion (op. cit.: 319) is that *"TQM does pass the discriminant validity test with reference to the writings of the TQM founders. But it is close to failing that test when one focuses on contemporary organisational practice. Many devices that are specifically eschewed by the founders are now commonly implemented in the name of TQM. And many practitioners now talk about 'involvement' and 'empowerment' as if they were synonymous with TQM and implement various employee involvement or empowerment interventions as part of a TQM package."* These findings lead to the core of Spencer's remarks (1994).

A systemic/process view on TQM. Spencer argues that, given the diversity of interpretations that exist on the construct, TQM practices have the potential to expand and to contribute to a better understanding of the three organisation models previously referred to. A comparison of these three models, more specifically their linkage to TQM-definitions and practices, is provided in Table 1. In addition to Hackman and Wageman's focus on the "fit" between the theory and practice of TQM, Spencer emphasises how the tension between them provides a nucleus to re-configure both the boundaries of the construct itself (making it more systemic or process-oriented instead of procedural) as well as the company's view on the process of organising.

Combining Hackman and Wageman's careful and methodical scrutiny with Spencer's reflective essay, we find that TQM is easily associated with organismic management concepts, with ample influence of mechanistic management approaches:

> *"One apperception that emerges from comparing TQM to the organismic management model is that TQM experts, specifically Deming and Juran, have been more successful than academics at generating precise ways of putting systems thinking into use."* (Spencer, 1994: 459)

The relationship between TQM and the cultural model of organising (see Table 1), which views the organisation as *"a collection of co-operative agreements entered into by individuals with free will (Chaffee, 1985), ... which is based on the assumption that the organisation's culture and its social environment are enacted or socially constructed by organisation members (Smircich and Stubbart, 1985),"* is less obvious.

If TQM is to be considered a set of tools and techniques, then, at first sight, it certainly has little in common with the cultural mode of organising. From a methodological perspective, TQM has strong functionalist features as it attempts to streamline individual behaviour to the demand of the larger organisational system. However, when organisations start seeing and using TQM as a vehicle for change, many comparisons with the cultural model of organisation can be made. Then TQM all of a sudden becomes a vehicle to construct and to frame a multiplex dialogue on work organisation and cross-functional integration throughout the company. By "multiplex" we mean that the dialogue involves a variety of actors and is conducted through multiple types of interactions (e.g. Rogers and Kincaid, 1981).

This view, of course, relaxes the original assumptions of the "founding fathers" of the TQM movement and puts the discriminant validity "problems" detected and reported by Hackman and Wageman (1995) in another perspective. More specifically, are the validity "problems" really problematic or are they just the consequence of the co-evolution between TQM and the model of organisation adopted by a company? Based on the previous analysis, we argue that this co-evolution enables an adaptive process where the meaning and the implementation of TQM develop (and change) gradually as the organisational context in which TQM becomes embedded, evolves. Or, as argued by Reger et al. (1994), implementing quality management principles usually implies a significant reframing of the organisation.

Reflecting further upon the relationship between TQM and the mechanistic mode of organising, it should be noted that proponents of the cultural model, like Barley and his colleagues (1988), do not fundamentally reject the notion of "control" over individual behaviour. They recognise, for instance, that culture provides a form of integration strategy. Hence, following this cultural paradigm, the TQM principles should not be rejected, but rather management's focus should be on the process of constructing and negotiating:

- the ends to which TQM will be used;
- the standards to evaluate the performance of the TQM principles;
- the way to distribute the benefits obtained via TQM;
- the interactive process of TQM deployment and organisational co-evolution.

TABLE 1:
TQM methodology and organisational models (Spencer, 1994)

TQM COMPONENTS	MECHANISTIC MODEL	ORGANISMIC MODEL	CULTURAL MODEL
Organisation goal:	Organisational efficiency & performance goals	Organisational survival (requires performance)	Meet individual needs & human development (requires system survival)
Definition of quality:	Conformance to standards	Customer satisfaction (requires conformance to standards)	Constituent satisfaction (requires customer satisfaction/conformance to standards)
Role/nature of environment:	Objective, focus on outside boundary	Objective, focus on inside boundary	Enacted with boundaries defined through relationships
Role of management:	Co-ordinate and provide visible control	Co-ordinate and provide invisible control by creating vision/system	Co-ordinate and mediate negotiations regarding vision, systems, rewards; lead by sharing control, demonstrating values
Role of employees:	Passive & follow orders	Reactive & self-control within system parameters	Active & self-control; participate in creation of vision
Structural rationality:	Chain of command: vertical communication & technical rationality	Process flow: horizontal + vertical communication & organisational rationality	Mutual adjustment in any direction & political rationality
Commitment toward change:	Stability is valued but learning arises from specialisation	Change and learning assist in adaptation	Change and learning are valued in themselves

A further scrutiny of Table 1 highlights managerial degrees of freedom to interprete the components of TQM, given the three models of organising. Managers who feel comfortable with mechanistic concepts will be more prone to stress the technical and procedural components of TQM. System-oriented managers may feel better at ease with the organic elements; while the cultural model is most useful in highlighting the "philosophy" behind TQM as well as the constituent processes that underpin the co-evolution of TQM and organisational mode.

To conclude, scholarly work has pointed to the multifaceted nature of the TQM-construct. Most important, it has contrasted the functionalist-positivist approach viewing TQM as a set of tools, techniques and procedures, with a more interpretative-constructivist approach that frames TQM as a vehicle to enact change processes within the organisation. This, however, implies that TQM is not merely regarded as a "prescription" toolkit to be introduced top-down throughout the organisation, but rather as a rallying point, whose meaning, boundaries and deployment are constructed gradually, via an iterative process, and interactively by the actors involved in and continuously drawn into the process.

CONSTRUCTING A TQM APPROACH AT UNION MINIERE R&D: UNDERSTANDING INNOVATION AS A PROCESS

As Union Minière started developing and designing its TQM frame, the R&D group was challenged to construct its proper TQM process. As outlined, R&D had been going through a fundamental re-structuring a couple of years before the current wave of corporate re-organisation. This re-structuring has introduced a partnership mode of defining and organising R&D activities. The central elements of this partnership model are summarised in Figure 1.

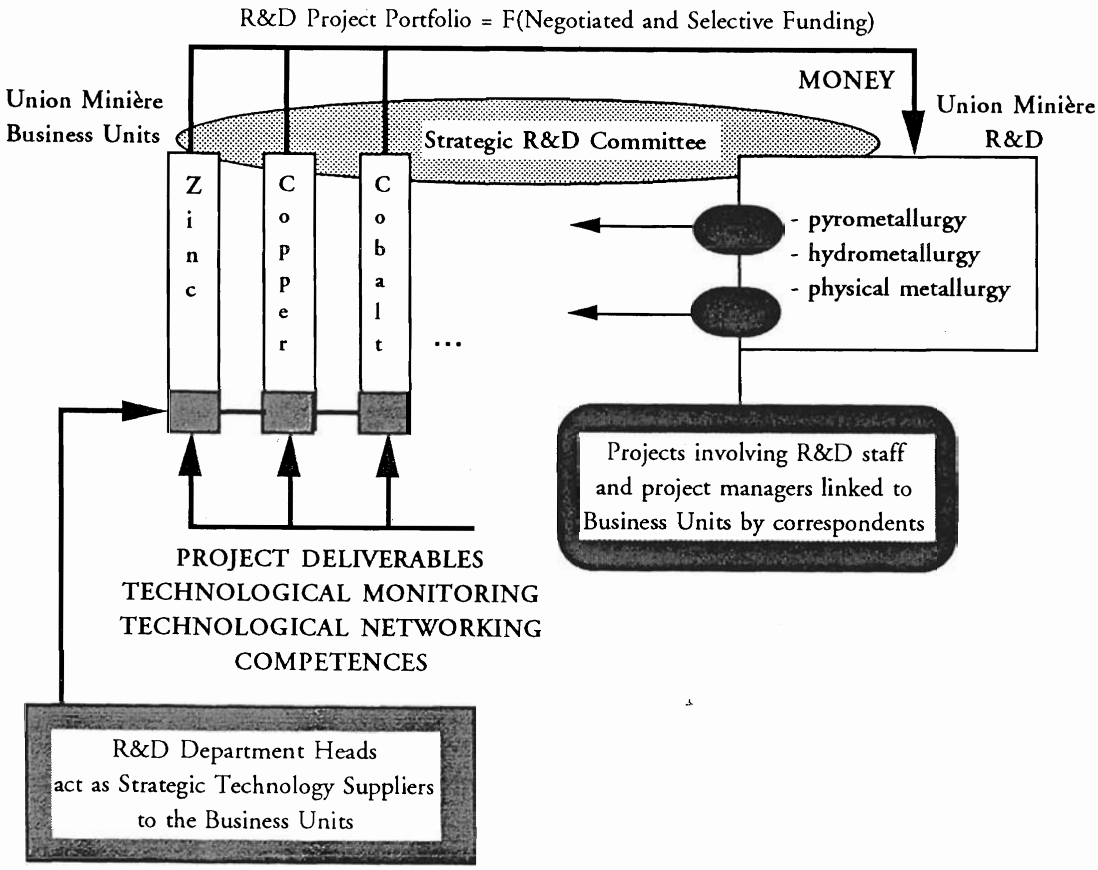
Organising R&D at Union Minière. At the strategic level, the Strategic R&D Committee (consisting of the business unit general managers, the corporate vice-president R&D and the R&D department heads) is the locus of negotiation, selection and monitoring of the R&D portfolio. It meets on a regular basis.

In order to further stimulate strategic interaction between the business units and the R&D organisation, each department head also acts as a "strategic supplier" to two-to-three different business units. This means that he is involved (for one-third of his professional time) in considering technological evolution and R&D topics potentially relevant to the business units he is servicing. In doing so, he acts as a Chief Technological Officer to these business units.

As is further derived from Figure 1, the R&D project portfolio is negotiated (on an annual basis) with the various business units. Once the projects have been selected and approved by the Strategic R&D Committee, each business unit funds its project(s). As a consequence, the model depicted in Figure 1 closely resembles the market control mode of funding corporate R&D, as described and discussed by Whittington (1991). In order to stimulate creativity, face-to-face communication and richness of inter-project information flows and interactions (Allen, 1977), R&D was deliberately organised as a central laboratory and hence, no physical decentralisation towards the different business units occurred.

The team-based structure, combined with the liaison role played by the business unit correspondents should compensate for the information losses that might occur between R&D and the business units because of physical and organisational distance. In addition, R&D staff and project managers, both at the junior and senior level, are assigned to technical assistance jobs in business unit plants, where they are also provided with office space. This context for boundary-spanning interaction has been created on purpose; as yet another process element to restrict information losses between R&D and the business units.

FIGURE 1:
The R&D process at Union Minière: strategic and operational fluxes



Notwithstanding this approach to stimulate a process of joint problem-definition and interactive problem-solving between R&D and the different business units, market failure in securing business unit funding for more uncertain, long-term R&D projects was experienced. Therefore, besides the monetary flows that start from the business units, a (limited) corporate flux of R&D funding was created in order to stimulate and support exploratory research activities. This corporate R&D funding is also administered and monitored via the Strategic R&D Committee. However, it is not accounted for by the business units' budgets.

At the operational levels, the project managers and the project members from R&D team up with collaborators from other functional areas. The central liaison role that has been created to foster the linkage between R&D project operations and the business units is the correspondent. He or she is a member of the business unit's staff and is entitled to define and to monitor the project jointly with the scientists and engineers involved. In addition, a R&D project management information system was custom-designed and -developed in order to provide adequate information and documentation on the status and the progress realised in each ongoing project. This is the context against which the R&D staff was challenged to develop a TQM-concept that would allow *"quality principles to be introduced during the technical innovation process."*

Quality in R&D: setting the stage. Sofar there has been only limited focus on the R&D function *sensu stricto* in the considerable amount of literature concerned with TQM. A few studies refer to the role of R&D as they unravel the needs for cross-functional integration and co-operation and the impact of the quality of the relationship between R&D and marketing as central drivers to a "high quality" innovation process. May and Pearson (1993) provide an overview of the introduction of TQM tools and techniques in R&D contexts; while Price and Chen (1993) emphasise the need for TQM in high-technology environments. Based on their overview of the introduction of TQM practices at fourteen companies in the U.K. and Canada, May and Pearson (1993) conclude that the factors which make the implementation of TQM harder in R&D than in other functions are:

- the more conceptual and intuitive nature of R&D activities;
- the non-repetitive character of the processes;
- the difficulty to assess "product" quality;
- the price of "non-conformance" is hard to evaluate.

As a consequence, according to May and Pearson, TQM should be adjusted to "suit" R&D. This adjustment should take into account R&D's need for flexibility, creativity and innovation. Spain (1996) goes one step further as he states that "to improve quality in R&D, improve the team work process." In other words, implementing quality principles in a R&D context necessitates a process-oriented rather than a procedure-based approach. Moreover, "no single process can be successfully and universally applied to all R&D organisations" (Davidson and Pruden, 1996).

How then should the quality management concept be defined, designed and implemented in a R&D setting? In order to provide an adequate answer to this question, though, it is necessary to first review the major relationships influencing R&D performance as they have been detected and documented by a long history of research in the management of technology area. Before embarking on this overview, though, it should be mentioned that the vast majority of scholarly studies takes an industrial stance toward the definition of R&D activities. R&D is thus interpreted from a rather broad perspective, including product and process development activities as well as more generic knowledge creation activities.

Performance in R&D. In Figure 2, we provide a summary (and simplified) overview of the key performance variables that have been documented in the R&D management literature. The pioneering work by Professor Thomas Allen (1977) has pointed to the critical influence of information flows and communication patterns on the performance of R&D activities. He examined the importance of intra-organisational and cross-functional information flows and communication patterns. However, he also pointed to the need for the innovative organisation to be well embedded in its broader technological environment. This embeddedness is symbolised by the presence of special roles during the innovation process, amongst which the gatekeeper figures prominently. A related research agenda, and one that has its origins in the development and the marketing of new products, further pointed to the importance of the design and the application of appropriate work organisation techniques and approaches in determining innovative performance, for instance:

- the use of flowchart-based decision and monitoring models of the innovation process, such as the process-dominant model, the stage-dominant model or the task-dominant model;
- the application of project-planning and -management techniques;
- the introduction of creativity and idea generation techniques like brainstorming;
- the development of selection methodologies that respond to the innovation's need for tolerating and handling uncertainty and ambiguity;
- the use and the design of grid-methodologies and techniques to define and to monitor innovation opportunities (e.g. product maturity grids, business growth matrices, quality function deployment matrices, ...)

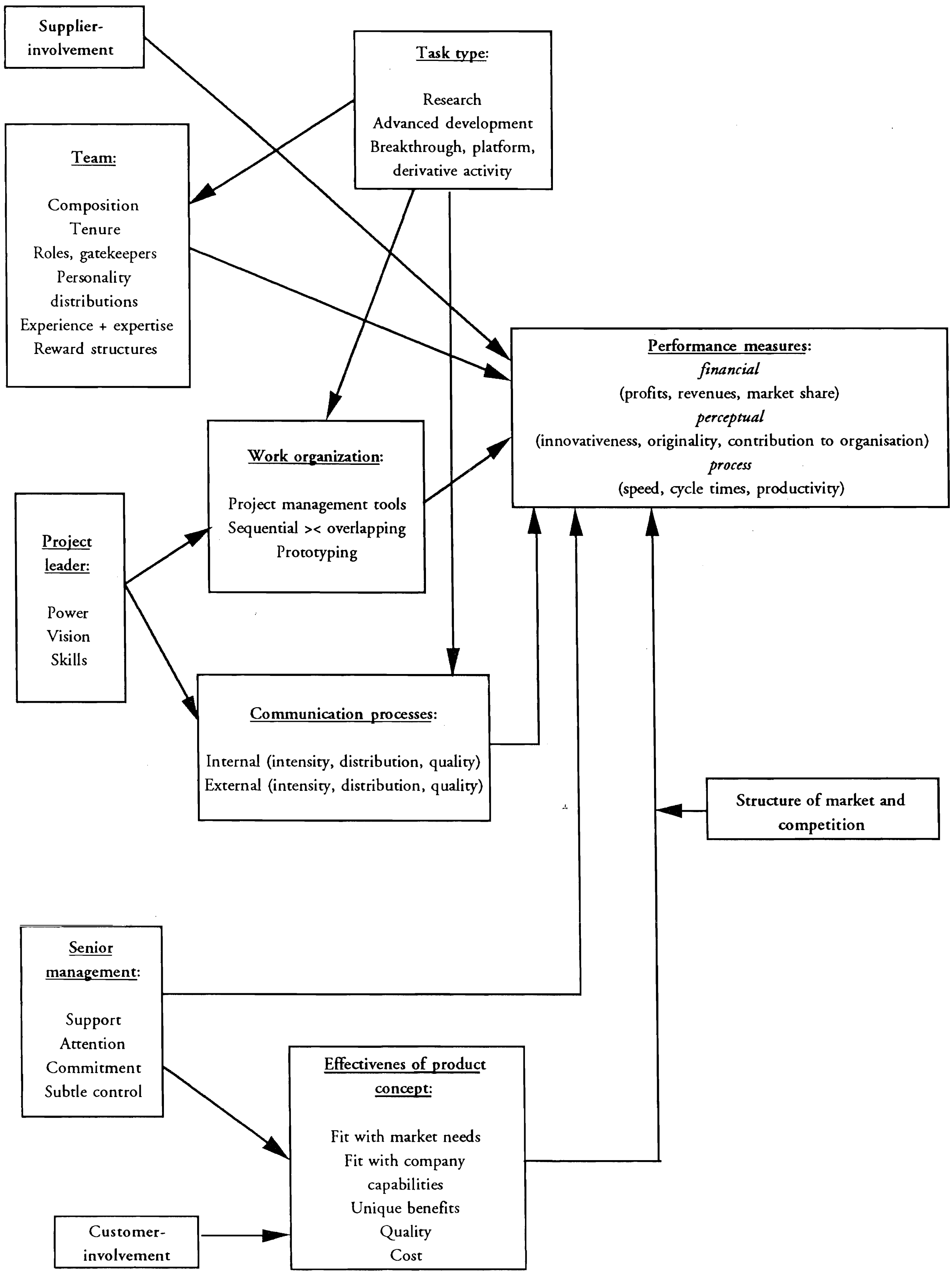
Important contributors to this particular stream of research are Bergen (1986), Cooper and Kleinschmidt (1995), Crawford (1983), Souder (1987), Twiss (1974) or Wheelwright and Clark (1992). As shown in Figure 2, both communication patterns and work organisation methodologies are at the heart of the performance framework. The mutual interaction and co-evolution of work organisation techniques and information flows is at the very heart of the management of the R&D and innovation process. Information flows are to be mediated and supported by an appropriate work organisation methodology. However, in order for these work methods to be deployed successfully, the necessary informal as well as formal information flows and communication patterns have to develop.

Over the last decade, in the wake of this seminal work, a myriad of parameters and relationships have been discussed and identified that exert a significant influence on various R&D performance standards. Recent discussions are to be found in the writings of Afuah and Bahram (1995), Brown and Eisenhardt (1995), Eisenhardt and Tabrizi (1995), or still, Iansiti (1995).

As further shown in Figure 2, the performance construct is complex and multi-dimensional. Performance relates to such rational, financial operationalisations as market shares and revenues that accrue from R&D and innovative activities. However, market shares and revenues only present one aspect of the performance concept. The second dimension relates to perceptual measures as the degree of innovativeness, or the innovation's contribution to the strategic mission of the organisation. The third route toward measuring performance refers to the internal efficiency of the innovative activity. It considers the extent to which the R&D and innovation process is efficiently managed in terms of throughput times along various phases of the innovation trajectory (e.g. time-to-concept, experimental problem-solving cycle times, time-to-ramp-up).

These dimensions of R&D and innovative performance (often operationalised at the project-level, although they can be aggregated at the portfolio-level) are influenced and leveraged by a myriad of parameters, as is further shown in Figure 2. As mentioned, communication patterns, information flows and work organisation techniques are at the heart of this framework. In addition, there are important roles to be fulfilled. Both senior management attitude and commitment, project leader traits and behavior, as well as team member characteristics, exert a strong influence on the performance of R&D and innovation activities. Moreover, these have to be embedded in an appropriate motivational context.

FIGURE 2:
Major relationships influencing the performance of R&D / innovative activities (project-level focus)



The involvement of external parties, more specifically suppliers and customers, is yet another well-known determinant of innovation success. For instance, von Hippel's research (1988) has well-documented the important role played by lead users and suppliers. The relative importance of their roles varies as to whom obtains the highest rents from investing in R&D and innovation. As can be glanced from Figure 2, the structure of the market or the degree of competition in the marketplace are yet another important parameter influencing success along the innovation journey. Turbulent market structures, marked by high degrees of monopolistic competition, strongly moderate the "optimal" organisation of the innovation process. Examples abound, e.g. the case of Quantum Corporation (1992). Quantum, active in the area of computer disk drives, experienced a turbulent, fast-evolving marketplace with fierce competition based on slightly differentiated product characteristics. This competitive environment necessitated an innovation function that is highly responsive to frequent changes in the marketplace. As a solution, Quantum based the organisation of its innovation process on flexible lateral (team-based) structures and appropriate incentive systems. These required each team member to act as a "cross-functional specialist" (although this may seem a *contradictio in terminis*). As those cross-functional specialists had to strike a balance between team versus individual performance, appropriate incentive systems were developed.

Finally, the uniqueness of the product concept and the complexity of the innovation task at hand (measured according to the typology developed by Wheelwright and Clark (1992) distinguishing between: advanced research and development, breakthrough, platform and derivative projects) significantly moderate the performance relationships detected during several decades of research into the innovation function and process.

TABLE 2:
The three models of organisation extended to the management of the innovation process

INNOVATION COMPONENTS	MECHANISTIC MODEL	ORGANISMIC MODEL	CULTURAL MODEL
Principal focus of innovation management:	Uncertainty reduction, via a rational plan approach involving multiple design reviews and stop/go points	Uncertainty reduction through cross-functional interaction and information exchange	Uncertainty reduction through joint problem-framing and -solving processes
Dominant approach to measure innovation performance:	Rational, based on financial revenues and market shares	Systemic, based on process-variables such as cycle times (requires revenues)	Holistic and integrative, based on perceptual measures (requires revenues and process)
Innovation methodology deployed:	Emphasis on decision flowcharts, supported by techniques related to project management	Emphasis on systemic techniques requiring cross-functional involvement, e.g. QFD	Emphasis on techniques that allow interactive problem-framing and -solution, e.g. experiential development methods
Implications for organisational approach:	Innovation management emphasises a functional "division" of specialties, implying a sequential view on the innovation trajectory	Innovation management emphasises lateral integration and coordination via matrix structures	Innovation management emphasises project and team-based structures as a vehicle to support a new venture creation process

To conclude this overview, we expand the three organisational models described in Table 1 to include the major components relevant to the management of the innovation process. This is done in Table 2. Extending the mechanistic model to the management of innovative activities leads to a rational planning approach (Brown and Eisenhardt, 1995). The emphasis is on uncertainty reduction using a rational, project-based management style supported by project management flowcharts involving multiple stop/go decision points or moments. Under this mode, performance is considered from a market/financial perspective. The organisation is geared toward functional specialisation and a rather sequential integration of the different activities occurring along the innovation trajectory. A comparison of Tables 1 and 2 reveals that the mechanistic model of organising the innovation journey will have little difficulty to absorb and to integrate the mechanistic definitions of TQM.

Similar parallels can be drawn when studying the organismic and cultural models. The organismic approach to innovation calls for cross-functional integration, information exchange and systemic performance monitoring. This should be reflected in the deployment of methodologies and techniques that support this cross-functionality. Quality function deployment (Hauser and Clausing, 1988 or Cohen, 1995) is considered a technique that fits this systemic approach.

Finally, the cultural approach is integrative and holistic. It requires the interactive, mutually adaptive framing and solving of problems. The emphasis is on a continuous adaptation and experimenting by the different (functional) backgrounds and groups involved in the process, supported by experiential development techniques as described by Eisenhardt and Tabrizi (1995). Under this mode, the different intra-organisational communities (e.g. R&D, manufacturing, marketing, sales) develop a deep understanding and appreciation of each others' agendas as well as of their framing and solving the problems related to the innovation challenge at hand. Under this mode, the emphasis is on interactivity and adaptation as a means to achieve a holistic management of the innovation process.

IMPLEMENTING A TQM APPROACH AT UNION MINIERE R&D

Based on the previous discussions and considerations, TQM was considered a process-issue rather than a procedural question at Union Minière R&D. The outcome of a series of discussions and meetings with the various stakeholders (R&D, Business Units and Corporate) revealed that the most important dimension of implementing TQM in R&D should relate to the quality of the cross-functional processes for problem-framing and -definition (as a starting point for high-quality project management). As a consequence, a systemic approach toward implementing TQM in R&D was favoured. Besides the introduction of the strategic decision process documented in Figure 1 as well as the development of an information system to support and document the various informal and formal information exchanges occurring during an innovation effort, it was decided to experiment with the technique of Quality Function Deployment (Hauser and Clausing, 1988 or Cohen, 1995) to enhance the quality of the problem-framing and -definition phase. This is the phase which occurs before projects "enter" the R&D portfolio according to the decision processes described and documented in Figure 1. Deploying the House-of-Quality methodology was hypothesised to stimulate cross-functional communication and, as a consequence, to enable a better and more precise framing of the project definition.

It is obvious that this view on introducing TQM in a R&D context adds to the discriminant validity problems as detected and reported by Hackman and Wageman (1995). However, it also points to Spencer's remarks (1994) on the interpretative flexibility in the delineation of the boundaries of TQM. By way of experiment, six potential R&D projects were framed and defined using the QFD-method during the period February-December 1996. Three of them concerned product innovations; while three involved process innovations. If developed and implemented, two of the three process innovations were believed to require major investments and might have a significant impact on Union Minière's competitive position. The four other potential projects were believed to be of a more moderate nature and impact. Hence, the six QFD experiments were judged (by all parties involved) to represent a realistic sample of the type and nature of innovative activities undertaken at Union Minière.

QFD AS A BUILDING BLOCK TO IMPLEMENT TQM AT UNION MINIERE: FINDINGS

The various phases as well as the persons and departments involved in the QFD-experiments were extensively studied, interviewed and monitored during the 10 month duration of the experiment. This analysis revealed quite a number of advantages of the QFD-technique as a tool to monitor and to support problem-framing and -definition. However, the analysis also reveals the problematic nature of introducing QFD/TQM in a R&D setting. This problematic nature does not imply that TQM principles cannot be implemented in R&D contexts. However, it points to the fact that the uncertain and ambiguous nature of R&D activities requires that TQM be implemented in a systemic manner, rather than in a mechanical and procedural manner. As a consequence, the mechanistic view on TQM may fit well the mechanistic model of the innovation process. However, as the emphasis along the innovation journey shifts from rational planning to cross-functional integration and problem-solving, this mechanistic approach becomes increasingly limited and even unsatisfactory.

QFD and actor-based interaction strategies. To each of the six pilot projects chosen as a vehicle to test QFD, a responsible "champion" from R&D was assigned. This approach was preferred since R&D first wanted to gain confidence with the introduction of QFD as a TQM building block before diffusing the methodology on a larger scale to all stakeholders involved in the innovation process. Hence, each potential project was framed and defined under the guidance of the responsible "champion" from R&D. This champion eventually had to come up with a completed QFD-matrix. However, he had the freedom to draw other stakeholders into the framing process at the speed and the moment of his choice. This resulted in some QFD-exercises being conducted in close and almost continuous interaction with the various stakeholders belonging to the commercial group at the business unit involved as well as at the manufacturing sites. Other QFD-applications were executed in a more isolated manner by the champion from R&D; with meetings and involvement from the various stakeholders being restricted and discrete in time rather than continuous and interactive. The choice between both types of interaction strategy depended heavily on the champion's perception of the willingness of the (business unit) stakeholders to participate in the definition process in an "open-minded" and "questioning" spirit and atmosphere; rather than being pre-determined about potential technological options and solution avenues. Although limited in occurrence, this pre-determined (business unit) view was experienced in one of the two major process innovation projects.

As a consequence, each R&D champion designed his or her proper interaction strategy vis-à-vis other stakeholders in order to develop and implement QFD as a TQM building block enabling the framing and the definition of technological innovations. Throughout this process, it was thus found that the QFD-concept (and its broader TQM implications) were useful to introduce quality principles in a R&D project environment; but, that the interaction strategies with the different stakeholders should be actor-designed. In other words, the TQM-process should allow enough degrees of freedom to R&D to handle the uncertainty and ambiguity that occur at the interface of the different functional groups (each of them bringing its prior experiences as well as its bounded rationality to the process) that interact during problem-framing and problem-definition.

QFD and clarity/consistency of need articulation. There was a general perception and experience shared by the stakeholders across all six projects that the introduction of a quality-approach significantly contributed to the clarity and consistency of the subsequent R&D project definitions. Although QFD was not experienced as influencing creativity, it did allow problems to be framed and reframed as new information and previous experiences from various stakeholders were drawn into the debate. This was most obvious in one of the process innovations where ideas obtained from research on battery products (based on the prior experience of the R&D champion) cross-fertilised with the manufacturing process needs as they were framed by the business unit. At the same time, though, this cross-fertilisation required the R&D champion to (temporarily) shield off his problem-framing and -solution avenue because it would not have been accepted by the business unit engineers as a viable alternative, given their (pre-determined) view on what ought to be the solution.

More specifically, the business unit point of view relied heavily on the need for process monitoring and instrumentation. The avenue that was gradually developed by the R&D champion implied a fundamental rethinking of the chemical properties of the refining process. His analysis revealed that, from a chemical perspective, process knowledge was underdeveloped. The QFD-approach ultimately allowed both points of view to be integrated with an emphasis on the better understanding of the chemical properties of the process; while at the same time introducing reliable instrumentation solutions.

Once again this points to the need for actor-designed interaction strategies as alluded to earlier in this section. In the end, all QFD-projects studied during this pilot-phase were judged highly satisfactory as far as definition clarity and consistency in problem-framing were concerned. Thus, QFD was experienced to introduce discipline and consistency during the definition of innovation efforts, although it can certainly not replace the need for a sound scientific methodology and associative creativity in order to arrive at problem-definitions and solution-alternatives. As one of the champions stated, QFD-TQM helps to structure the systemic nature of innovative work, though it should be supported by a solid scientific and engineering expertise.

QFD and quality management as knowledge transfer tools. Given the consistency and clarity just mentioned, there was a quasi-unanimity that QFD might prove a helpful instrument to document new information and knowledge generated during technological innovations. As a consequence, several persons involved raised the potential use of QFD as a learning tool, especially for young scientists and engineers who still have to familiarise with the nature of the problems and the technical/business agendas relevant to Union Minière. QFD as well as the philosophy behind the introduction of TQM in a R&D environment can serve this learning perspective. This finding is further corroborated by the recent insights gained from the work of Senge and his colleagues (1994). Some participants to the pilot-project therefore considered QFD's potential to become a coaching element in the training of new recruits and young staff scientists and engineers.

QFD and communication processes. Although we have to admit the need for the development of actor-designed interaction strategies, the respondents were unanimous as to their experience that QFD enabled informal as well as formal cross-functional communication. This enabling role was judged performing its best in the absence of large power distances between the stakeholders involved. Moreover, and this brings us to the fuzzy front-end of the innovation process, QFD was experienced to be at its best when a certain level of ambiguity identification (and not necessarily reduction) both through informal communication and through technical experimentation had preceded the QFD-exercise. This was a well-articulated and consistent finding across all six pilot projects studied. A certain "problem-history" was judged useful to the application of the QFD-methodology. In addition, almost all respondents reported that it might be extremely difficult to start the QFD exercise from scratch, using a blank sheet with only rows and columns left to be filled out by the stakeholders involved in a joint interaction process. To conclude, QFD was experienced to support cross-functional communication, although a "history" of informal communication and experimentation provides a useful underpinning.

QFD and innovation process speed. There also was a general consensus that, because of the systemic and structuring nature of the QFD methodology, the speed at which the innovation topics were framed and defined increased viz. past experience. QFD further helps to reveal and identify gaps in the stakeholders' understanding of market and technology. It forces them to be as explicit, exhaustive and complete as possible as to their expectations and their capabilities in a first step towards their (cross-functional) alignment. As a consequence, QFD might help fuse the concepts of knowledge and quality. When articulated in such a manner, QFD introduces a truly systemic view on quality in R&D. To paraphrase Majchrzak and Wang (1996), it helps *"breaking the functional mind-set in a process organisation."*

QFD as collective memory. In line with the previous remarks on QFD as a knowledge transfer tool, a number of respondents emphasised the potential contribution of QFD to "construct" a collective memory on problem-framing and -definition at Union Minière.

QFD and TQM & the need for training and education. Finally, all participants in the six pilot projects unanimously agreed that QFD in specific and TQM at large should be accompanied by a continuous process of training and education.

CONCLUSIONS

This paper has discussed the introduction of TQM-principles in specific R&D context. It has been argued that TQM (operationalised via a QFD-methodology as a (major) building block) is a powerful concept to induce cross-functional integration and problem-framing along the innovation trajectory. This, however, implies that TQM principles be designed and developed in alignment with the systemic requirements of the innovation process. More specifically, Union Minière's experimentation with Quality Function Deployment to stretch quality levels in framing and defining potential R&D projects, has illustrated how the (limited) introduction of TQM principles has a positive impact upon the fuzzy front-end of the innovation process. It also illustrates how work organisation techniques that aim at improving "quality," impact upon the communication patterns and interaction strategies during innovation. This "mutuality" between patterns of communication and work organisation was shown to be at the heart of the findings of several decades of research on the performance determinants of R&D and innovation activities.

As a consequence, QFD (as detected during our research) not only impacts upon the quality of framing and defining relevant problems for R&D, but also upon the way (individual) strategies for boundary-spanning interaction are enacted by the various actors involved; and hence, upon the fundamental relationships relevant to the performance of R&D and innovation activities. These findings are believed to signal four important lessons to R&D managers attempting to implement TQM principles.

First of all, a purely mechanistic approach toward TQM will probably fail since it neglects the systemic nature of the innovation process. Cross-functional problem-definition requires the freedom to frame the problem from diverse perspectives; accompanied by the development of appropriate interaction strategies to better understand problem-framing by the various stakeholders. This will be difficult to achieve when QFD/TQM procedures are considered only to "mechanise" framing.

Second, and in line with Spencer's arguments (and opposed to the "problems" detected by Hackman and Wageman), quality principles can stretch the boundaries of framing, defining and organising R&D activities. R&D management should take full advantage of this potential, rather than restrict the introduction of TQM principles and methods to their procedural tenets.

Third, when monitored properly, QFD/TQM helps to continuously upgrade the cross-functional work (and knowledge creation) process in an innovative organisation. Our research has shown that this is a gradual, iterative process. It will indeed take several iterations and many more interactions before all stakeholders are determined to fully participate in the QFD-process just analysed.

Fourth, although the introduction of quality principles requires clarity and consistency, the various individuals and groups involved in the innovation effort should at the same time receive enough autonomy from R&D management to design situational versions of those same principles in order to maximise their framing and definition potential.

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